

# Network for transfer of an arbitrary $n$ -qubit atomic state via cavity QED

Zhan-jun Zhang<sup>1,2</sup>

<sup>1</sup> School of Physics & Material Science, Anhui University, Hefei 230039, China

<sup>2</sup> Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan 430071, China

Email: zhangzj@wipm.ac.cn

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I show a scheme which allows a perfect transfer of an unknown single-qubit atomic state from one atom to another by letting two atoms interact simultaneously with a cavity QED. During the interaction between atom and cavity, the cavity is only virtually excited and accordingly the scheme is insensitive to the cavity field states and cavity decay. Based on this scheme, a network for transfer of an arbitrary single-qubit atomic state between atoms is engineered. Then the scheme is generalized to perfectly transfer an arbitrary 2-qubit atomic state and accordingly a network for transfer of an arbitrary 2-qubit atomic state is designed. At last, it is proven that the schemes can be generalized to an arbitrary  $n$  ( $n \geq 3$ )-qubit atomic state transfer case and a corresponding network is also proposed.

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## I. Introduction

No cloning theorem forbids a perfect copy of an arbitrary unknown quantum state. How to interchange different resources has ever been a question in quantum computation and quantum information. In 1993, Bennett *et al*[1] first presented a quantum teleportation scheme. In the scheme, an arbitrary unknown quantum state in a qubit can be teleported to a distant qubit with the the help of Einstein-Podolsky-Rosen (EPR) pair. Their work showed in essence the interchangeability of different resources in quantum mechanics. Hence, after Bennett *et al*'s pioneering work in 1993, quantum teleportation has attracted many attentions[2-27]. However, in the experimental aspects, since the complete Bell state set can not be discriminated so far, teleportation can only be achieved in a nondeterministic manner. As a matter of fact, one can transfer quantum states ont only by the method of teleportation[1] but also by quantum state transfer network[28-32]. The basic idea of a quantum network is to transfer a quantum state from one node to another with aid of a *messenger* such that it arrives intact. In this process, the unknown state initially in a node is first transferred to the messenger, then the messenger carrying the unknown state goes ahead to the destination node. When it arrives, the unknown state in the messenger is further transferred to the destination node. For different networks, messengers may be different. For examples, in Ref.[28-30], the messenger is a photon, which delivers the unknown state from one atom to another, while in Ref.[32] the messenger is an atom, which delivers an unknown state from a cavity to another. In fact, recently quantum network has attracted some attentions and interests continuously increase[28-35]. There are various physical systems can that can serve as quantum networks, one of them being the atom-cavity system[28-32]. In this paper I will propose a scheme for transfer of an unknown state from one atom to another via direct interaction with each other in a cavity. I will focus on the situation in which state transfer is perfect. Hence in the designed network the unknown state can be transferred in a deterministic way to another atom which is elsewhere. The distinct advantage of the present scheme is that during the passage of the atoms through the cavity field, the cavity is only virtually excited. No

transfer of quantum information will occur between the atoms and cavity. The present scheme does not require any measurement on atoms.

The present paper is organized as follows. In section 2, I describe the scheme for a perfect transfer of an unknown single-qubit atomic state from one atom to another by letting two atoms interact simultaneously with a cavity QED. As a result of the scheme, a network for transfer of an arbitrary single-qubit atomic state between atoms is engineered. In section 3, the scheme is generalized to perfectly transfer an arbitrary 2-qubit atomic state and accordingly a network for transfer of an arbitrary 2-qubit atomic state is designed. A prove of an arbitrary  $n(n \geq 3)$ -qubit atomic state can be perfectly transferred in a similar network is shown in the section 4. A brief summary is given in the last section.

## II. Network for transfer of an arbitrary single-qubit atomic state via cavity QED

Assume that the atom 1 is in a state,

$$|\psi\rangle_1 = \alpha|0\rangle_1 + \beta|1\rangle_1, \quad (1)$$

where  $\alpha$  and  $\beta$  are *unknown* arbitrary coefficients,  $|\alpha|^2 + |\beta|^2 = 1$ .  $|1\rangle$  and  $|0\rangle$  are the excited and ground states of the atom, respectively. This arbitrary state in the atom 1 needs to be transferred to another atom which is elsewhere.

Before giving the present state transfer scheme it is helpful to briefly review the teleportation scheme proposed by Ye and Guo[23]. The Ye-Guo scheme includes the following steps (cf., figure 1(a)): (i) Two identical two-level atoms 2 and 3 are prepared in the state  $|1\rangle_2$  and  $|0\rangle_3$ , respectively. Each of the two identical cavities  $C_1$  and  $C_2$  is prepared in a vacuum state. (ii) Let atoms 2 and 3 interact simultaneously with the cavity  $C_1$ . By the way, in the case  $\Delta \gg g$ , no energy exchange between the atomic system and the cavity exists, where  $\Delta$  is the detuning between the atomic transition frequency  $\omega_0$  and the cavity frequency  $\omega$ , and  $g$  is the atom-cavity coupling constant. In the interaction picture, the effective Hamiltonian for this system is [36]

$$H_e = \lambda \left( \sum_{k=1}^2 |1\rangle_{kk} \langle 1| + \sum_{k,j=1, k \neq j}^2 S_k^+ S_j^- \right), \quad (2)$$

where  $\lambda = g^2/\Delta$ ,  $S_k^+ = |1\rangle_{kk} \langle 0|$ ,  $S_k^- = |0\rangle_{kk} \langle 1|$ , and  $|1\rangle_k$  and  $|0\rangle_k$  are the excited and ground states of the  $k$ th atom, respectively. For the following different initial atomic states, they evolve as follows,

$$|1\rangle_k |0\rangle_j \rightarrow e^{-i\lambda t} (\cos \lambda t |1\rangle_k |0\rangle_j - i \sin \lambda t |0\rangle_k |1\rangle_j), \quad (3)$$

$$|0\rangle_k |1\rangle_j \rightarrow e^{-i\lambda t} (\cos \lambda t |0\rangle_k |1\rangle_j - i \sin \lambda t |1\rangle_k |0\rangle_j), \quad (4)$$

$$|1\rangle_k |1\rangle_j \rightarrow e^{-2i\lambda t} |1\rangle_k |1\rangle_j, \quad (5)$$

$$|0\rangle_k |0\rangle_j \rightarrow |0\rangle_k |0\rangle_j, \quad (6)$$

where  $t$  is the interaction time. With the choice of  $\lambda t = \pi/4$ , the initial state of the two-atom (atoms 2 and 3) system evolves to a maximally entangled state,

$$|\psi\rangle_{23} = \frac{e^{-i\pi/4}}{\sqrt{2}} (|1\rangle_2 |0\rangle_3 - i |0\rangle_2 |1\rangle_3). \quad (7)$$

Note that in the equations 4-7 of Ref.[23] an unimportant overall factor  $e^{-i\pi/4}$  is missed and a factor  $\frac{1}{\sqrt{2}}$  should be included in the last term of the equation 7. (iii) Let atoms 1 and 2 interact simultaneously

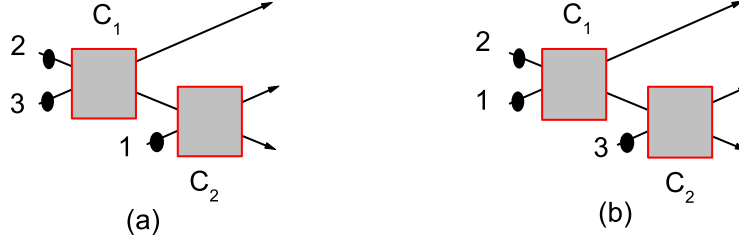


FIG. 1: The black dots represent atoms. The grey box stands for cavity. The initial states of the atoms 2 and 1 are respectively  $|1\rangle_2$  and  $\alpha|0\rangle_1 + \beta|1\rangle_1$  before they pass through the cavities  $C_1$  and  $C_2$ . (a) The initial state of the atom 3 is  $|0\rangle_3$ . The interaction time of the two atoms interact simultaneously with each cavity satisfies  $\lambda t = \pi/4$ . (b) The initial state of the atom 3 is  $|1\rangle_3$ . The interaction time of the two atoms interact simultaneously with each cavity satisfies  $\lambda t = \pi/2$ . See text for detail.

with the cavity  $C_2$  with the interaction time such that  $\lambda t = \pi/4$ , then the state of the whole atomic system becomes

$$|\psi\rangle_{123} = \frac{-i}{\sqrt{2}} \left\{ \frac{1}{\sqrt{2}}|0\rangle_1|1\rangle_2(\alpha|0\rangle_3 - \beta|1\rangle_3) + e^{-i\pi/4}\beta|1\rangle_1|1\rangle_2|0\rangle_3 \right. \\ \left. + \frac{1}{\sqrt{2}}|1\rangle_1|0\rangle_2(\alpha|0\rangle_3 + \beta|1\rangle_3) + e^{-i\pi/4}\alpha|0\rangle_1|0\rangle_2|1\rangle_3 \right\}. \quad (8)$$

(iv) If the states of the atoms 1 and 2 are detected to be  $|1\rangle_1$  and  $|0\rangle_2$  respectively after they pass through the cavity  $C_2$ , then the state of atom 3 is exactly the unknown state initially in atom 1 after its passage through the cavity  $C_1$ . If the state of the atoms 1 and 2 is  $|0\rangle_1|1\rangle_2$ , then atom 3 needs to perform a phase transformation to recover the initial state of atom 1. If the atoms 1 and 3 are detected in the state  $|1\rangle_1|1\rangle_2$  or  $|0\rangle_1|0\rangle_2$ , the teleportation fails. Hence, in the Ye-Guo scheme [23], the teleportation is *nondeterministic* and its success probability is  $1/2$ .

Now let us move to present my scheme. In my scheme almost the same device as that in Ye-Guo's scheme are employed. However, it allows a *perfect* transfer of the unknown state in atom 1 to atom 3. One will see this later. My scheme includes the following steps (cf., figure 1(b)): (i) This step is same as that in the Ye-Guo scheme except that the two-level atom 3 is prepared in the state  $|1\rangle_3$  instead of  $|0\rangle_3$ . (ii) Let the atoms 1 and 2 instead of the atoms 2 and 3 in the Ye-Guo scheme interact simultaneously with the cavity 1. The initial state of the atoms 1 and 2 before their passage through the cavity  $C_1$  is

$$|\psi\rangle_{12} = (\alpha|0\rangle_1 + \beta|1\rangle_1)|1\rangle_2. \quad (9)$$

After an interaction time  $t$ , the whole system evolves to

$$|\psi'\rangle_{12} = \alpha e^{-i\lambda t}(\cos \lambda t|0\rangle_1|1\rangle_2 - i \sin \lambda t|1\rangle_1|0\rangle_2) + \beta e^{-2i\lambda t}|1\rangle_1|1\rangle_2. \quad (10)$$

Different from the interaction time in the Ye-Guo schme, the interaction time in the present scheme is doubled, that is,  $\lambda t = \pi/2$  is chosen. Then the final state of the atoms 1 and 2 after the evolution is

$$|\psi''\rangle_{12} = -|1\rangle_1(\alpha|0\rangle_2 + \beta|1\rangle_2). \quad (11)$$

Obviously, the unknown state initially in the atom 1 is transferred to the atom 2 after they interact in the cavity  $C_1$  with the certain time. (iii) Similarly, if atoms 2 and 3 simultaneously interact with the

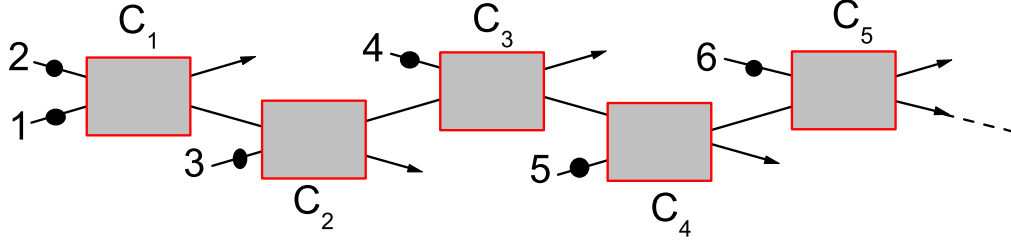


FIG. 2: The black dots represent atoms. The grey box stands for cavity. The initial states of the atom 1 is  $\alpha|0\rangle + \beta|1\rangle$  and other are in  $|1\rangle$ 's before they pass through cavities. The interaction time of each two atoms interact simultaneously with the corresponding cavity satisfies  $\lambda t = \pi/2$ . See text for detail.

cavity  $C_2$  with the interaction time satisfying  $\lambda t = \pi/2$ , then the final state of the total system is

$$|\psi\rangle_{123} = |1\rangle_1 |1\rangle_2 (\alpha|0\rangle_3 + \beta|1\rangle_3). \quad (12)$$

One can easily find that, after the interactions, the unknown state initially in the atom 1 is further transferred to the atom 3, and the atoms 1, 2 and 3 do not entangle with each other. Hence the measurements on the atoms 1 and 2, which need to be performed in the Ye-Guo scheme to collapse the entire state and accordingly to get or reconstruct the unknown state, are unnecessary in the present scheme. If the similar procedures are repeated, then the unknown state can be transferred to an atom which is elsewhere (cf., figure 2). Thus far, a network for transfer of an arbitrary single-qubit atomic state between atoms is established.

Compared to the Ye-Guo teleportation scheme[23], the distinct advantages of the present scheme are: (1) The present scheme provides a *deterministic* way to transfer the unknown state between atoms via cavity QED; (2) Measurements on other atoms are unnecessary; (3) After the whole transfer process all atoms are still in their initially prepared states (i.e., the excited states) except for the first and last atoms, hence they can be reused for next state transfer in the network. (4) Each cavity acts in essence as a SWAP gate except for an overall unimportant factor. Moreover, as same as stressed by Ye and Guo in Ref.[23], during the interaction between atom and cavity, the cavity is only virtually excited and thus the present scheme is insensitive to the cavity field states and cavity decay. This is also an advantage of the present scheme.

### III. Network for transfer of an arbitrary 2-qubit atomic state via cavity QED

Now let us generalize the above scheme to an arbitrary two-qubit atomic state transfer scheme. A two-qubit atomic state which needs to be transferred is written as

$$|\psi\rangle_{a_1 a_2} = \alpha|0\rangle_{a_1}|0\rangle_{a_2} + \beta|0\rangle_{a_1}|1\rangle_{a_2} + \gamma|1\rangle_{a_1}|0\rangle_{a_2} + \delta|1\rangle_{a_1}|1\rangle_{a_2}, \quad (13)$$

where  $a_1$  and  $a_2$  label two atoms,  $\alpha, \beta, \gamma$  and  $\delta$  are *unknown* complex coefficients, and I assume  $|\psi\rangle_{a_1 a_2}$  to be normalized. This generalized scheme contains the following steps (cf., figure 3): (i) Two atoms  $b_1$  and  $b_2$  are prepared in excited states, i.e.,  $|1\rangle_{b_1}$  and  $|1\rangle_{b_2}$ . Cavities  $C_{11}$  and  $C_{21}$  are in vacuum modes. Then the initial state of the system including atoms  $a_1, a_2, b_1$  and  $b_2$  is

$$|\psi\rangle_{a_1 a_2 b_1 b_2} = (\alpha|0\rangle_{a_1}|0\rangle_{a_2} + \beta|0\rangle_{a_1}|1\rangle_{a_2} + \gamma|1\rangle_{a_1}|0\rangle_{a_2} + \delta|1\rangle_{a_1}|1\rangle_{a_2})|1\rangle_{b_1}|1\rangle_{b_2}. \quad (14)$$

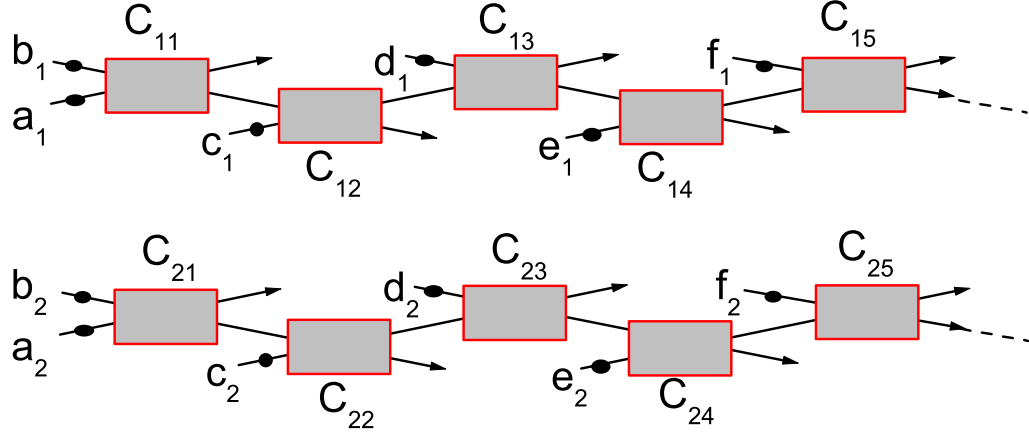


FIG. 3: The network for transfer of an arbitrary 2-qubit state. See text for detail.

It can be rewritten as

$$|\psi\rangle_{a_1 a_2 b_1 b_2} = (\alpha|0\rangle_{a_1} + \gamma|1\rangle_{a_1})|1\rangle_{b_1}|0\rangle_{a_2}|1\rangle_{b_2} + (\beta|0\rangle_{a_1} + \delta|1\rangle_{a_1})|1\rangle_{b_1}|1\rangle_{a_2}|1\rangle_{b_2}. \quad (15)$$

(ii) Let atoms  $a_1$  and  $b_1$  interact simultaneously with the cavity  $C_{11}$  with an interaction time  $t$  such that  $\lambda t = \pi/2$ , then according to the scheme in the last section, the state of the system evolves to

$$|\psi'\rangle_{a_1 a_2 b_1 b_2} = -|1\rangle_{a_1}(\alpha|0\rangle_{b_1} + \gamma|1\rangle_{b_1})|0\rangle_{a_2}|1\rangle_{b_2} - |1\rangle_{a_1}(\beta|0\rangle_{b_1} + \delta|1\rangle_{b_1})|1\rangle_{a_2}|1\rangle_{b_2}. \quad (16)$$

It can be rewritten as

$$|\psi'\rangle_{a_1 a_2 b_1 b_2} = -|1\rangle_{a_1}|0\rangle_{b_1}(\alpha|0\rangle_{a_2} + \beta|1\rangle_{a_2})|1\rangle_{b_2} - |1\rangle_{a_1}|1\rangle_{b_1}(\gamma|0\rangle_{a_2} + \delta|1\rangle_{a_2})|1\rangle_{b_2}. \quad (17)$$

(iii) Similarly, let atoms  $a_2$  and  $b_2$  interact simultaneously with the cavity  $C_{21}$  with an interaction time  $t$  such that  $\lambda t = \pi/2$ , then the state of the system evolves to

$$\begin{aligned} |\psi'\rangle_{a_1 a_2 b_1 b_2} &= |1\rangle_{a_1}|1\rangle_{a_2}|0\rangle_{b_1}(\alpha|0\rangle_{b_2} + \beta|1\rangle_{b_2}) + |1\rangle_{a_1}|1\rangle_{a_2}|1\rangle_{b_1}(\gamma|0\rangle_{b_2} + \delta|1\rangle_{b_2}) \\ &= |1\rangle_{a_1}|1\rangle_{a_2}(\alpha|0\rangle_{b_1}|0\rangle_{b_2} + \beta|0\rangle_{b_1}|1\rangle_{b_2} + \gamma|1\rangle_{b_1}|0\rangle_{b_2} + \delta|1\rangle_{b_1}|1\rangle_{b_2}) \\ &= |1\rangle_{a_1}|1\rangle_{a_2}|\psi\rangle_{b_1 b_2}. \end{aligned} \quad (18)$$

Obviously, the unknown two-qubit atomic state initially in the atoms  $a_1$  and  $a_2$  is transferred to the atoms  $b_1$  and  $b_2$ , and vice versa. Hence the two cavities  $C_{11}$  and  $C_{21}$  act as a SWAP gate of two-qubit atomic states. (iii) If similar procedures are repeated (cf., figure 3), then the arbitrary two-qubit atomic state can be further transferred to  $c_1$  and  $c_2$ ,  $d_1$  and  $d_2$ , and so on (cf., Figure 3). Thus a network for transfer of an arbitrary 2-qubit atomic state between atoms is established.

One can easily find that the advantages mentioned in last section remain for this generalized scheme. Moreover, in Ref.[23], Ye and Guo have proposed a scheme for teleportation of a *special* class of unknown two-qubit atomic states by using a GHZ atomic state. The successful teleportation can only be achieved with a probability of  $1/2$ . In contrast, in the present scheme the transfer of an *arbitrary* two-qubit atomic states but not a special class of two-qubit entangled atom states can be achieved *deterministically* and no complicated initial states need to be prepared. These are additional advantages

of this generalized scheme.

#### IV. Network for transfer of an arbitrary $n(n \geq 3)$ -qubit atomic state via cavity QED

Now let us generalize the above scheme to an arbitrary  $n(n \geq 3)$ -qubit atomic state transfer scheme. In the following I will prove that, if an arbitrary  $(n-1)(n \geq 3)$ -qubit quantum state can be transferred successfully by using  $n-1$  cavities in a network, then an arbitrary  $n(n \geq 3)$ -qubit quantum state can be transferred successfully via using  $n$  cavities. An arbitrary  $n(n \geq 3)$ -qubit atomic state which needs to be transferred is written as

$$|\xi\rangle_{a_1 a_2 \dots a_n} = \sum_{m_n=0}^1 \dots \sum_{m_2=0}^1 \sum_{m_1=0}^1 C_{m_1 m_2 \dots m_n} |m_1\rangle_{a_1} |m_2\rangle_{a_2} \dots |m_n\rangle_{a_n}, \quad (19)$$

where  $C$ 's are complex coefficients and  $|\xi\rangle_{a_1 a_2 \dots a_n}$  is assumed to be normalized. It can be decomposed as

$$\begin{aligned} |\xi\rangle_{a_1 a_2 \dots a_n} &= |0\rangle_{a_n} \left( \sum_{m_{n-1}=0}^1 \dots \sum_{m_2=0}^1 \sum_{m_1=0}^1 C_{m_1 m_2 \dots m_{n-1} 0} |m_1\rangle_{a_1} |m_2\rangle_{a_2} \dots |m_{n-1}\rangle_{a_{n-1}} \right) \\ &+ |1\rangle_{a_n} \left( \sum_{m_{n-1}=0}^1 \dots \sum_{m_2=0}^1 \sum_{m_1=0}^1 C_{m_1 m_2 \dots m_{n-1} 1} |m_1\rangle_{a_1} |m_2\rangle_{a_2} \dots |m_{n-1}\rangle_{a_{n-1}} \right) \\ &\equiv |0\rangle_{a_n} \zeta_{a_1 a_2 \dots a_{n-1}} + |1\rangle_{a_n} \zeta'_{a_1 a_2 \dots a_{n-1}}. \end{aligned} \quad (20)$$

Here  $\zeta_{a_1 a_2 \dots a_{n-1}}$  and  $\zeta'_{a_1 a_2 \dots a_{n-1}}$  are in essence arbitrary  $(n-1)$ -qubit states, respectively.

Suppose there are  $n$  atoms labelling as  $b_1, b_2, \dots, b_n$  and each is prepared in a state  $|1\rangle$ . Then the initial joint state of the  $2n$  atoms (i.e.,  $a_1, a_2, \dots, a_n, b_1, b_2, \dots, b_n$ ) is

$$\begin{aligned} &|\xi\rangle_{a_1 a_2 \dots a_n} |1\rangle_{b_1} |1\rangle_{b_2} \dots |1\rangle_{b_{n-1}} |1\rangle_{b_n} \\ &= |0\rangle_{a_n} \zeta_{a_1 a_2 \dots a_{n-1}} |1\rangle_{b_1} |1\rangle_{b_2} \dots |1\rangle_{b_{n-1}} |1\rangle_{b_n} + |1\rangle_{a_n} \zeta'_{a_1 a_2 \dots a_{n-1}} |1\rangle_{b_1} |1\rangle_{b_2} \dots |1\rangle_{b_{n-1}} |1\rangle_{b_n}. \end{aligned} \quad (21)$$

It has previously been supposed that an arbitrary  $(N-1)(N \geq 3)$ -qubit quantum state can be transferred successfully via using  $n-1$  cavities in a network. This means that the above initial state can evolve to the following state,

$$\begin{aligned} &|0\rangle_{a_n} |1\rangle_{a_1} |1\rangle_{a_2} \dots |1\rangle_{a_{n-1}} \zeta_{b_1 b_2 \dots b_{n-1}} |1\rangle_{b_n} + |1\rangle_{a_n} |1\rangle_{a_1} |1\rangle_{a_2} \dots |1\rangle_{a_{n-1}} \zeta'_{b_1 b_2 \dots b_{n-1}} |1\rangle_{b_n} \\ &= |1\rangle_{a_1} |1\rangle_{a_2} \dots |1\rangle_{a_{n-1}} (\zeta_{b_1 b_2 \dots b_{n-1}} |0\rangle_{a_n} + \zeta'_{b_1 b_2 \dots b_{n-1}} |1\rangle_{a_n}) |1\rangle_{b_n}. \end{aligned} \quad (22)$$

Now let the atoms  $a_n$  and  $b_n$  interact simultaneously with the  $n$ th cavity, then according to equations 3 and 4 the state of the system evolves as

$$\begin{aligned} &|1\rangle_{a_1} |1\rangle_{a_2} \dots |1\rangle_{a_{n-1}} \left[ \zeta_{b_1 b_2 \dots b_{n-1}} e^{-i\lambda t} (\cos \lambda t |0\rangle_{a_n} |1\rangle_{b_n} - i \sin \lambda t |1\rangle_{a_n} |0\rangle_{b_n}) \right. \\ &\quad \left. + \zeta'_{b_1 b_2 \dots b_{n-1}} e^{-2i\lambda t} |1\rangle_{a_n} |1\rangle_{b_n} \right]. \end{aligned} \quad (23)$$

With a choice of  $\lambda t = \pi/2$ , then the state is

$$- |1\rangle_{a_1} |1\rangle_{a_2} \dots |1\rangle_{a_{n-1}} |1\rangle_{a_n} (\zeta_{b_1 b_2 \dots b_{n-1}} |0\rangle_{b_n} + \zeta'_{b_1 b_2 \dots b_{n-1}} |1\rangle_{b_n}) = - |1\rangle_{a_1} |1\rangle_{a_2} \dots |1\rangle_{a_n} |\xi\rangle_{b_1 b_2 \dots b_n}. \quad (24)$$

The equations 19-24 have shown an arbitrary  $n(n \geq 3)$ -qubit quantum state can be transferred successfully via using  $n$  cavities provided that an arbitrary  $(n-1)(n \geq 3)$ -qubit quantum state can be

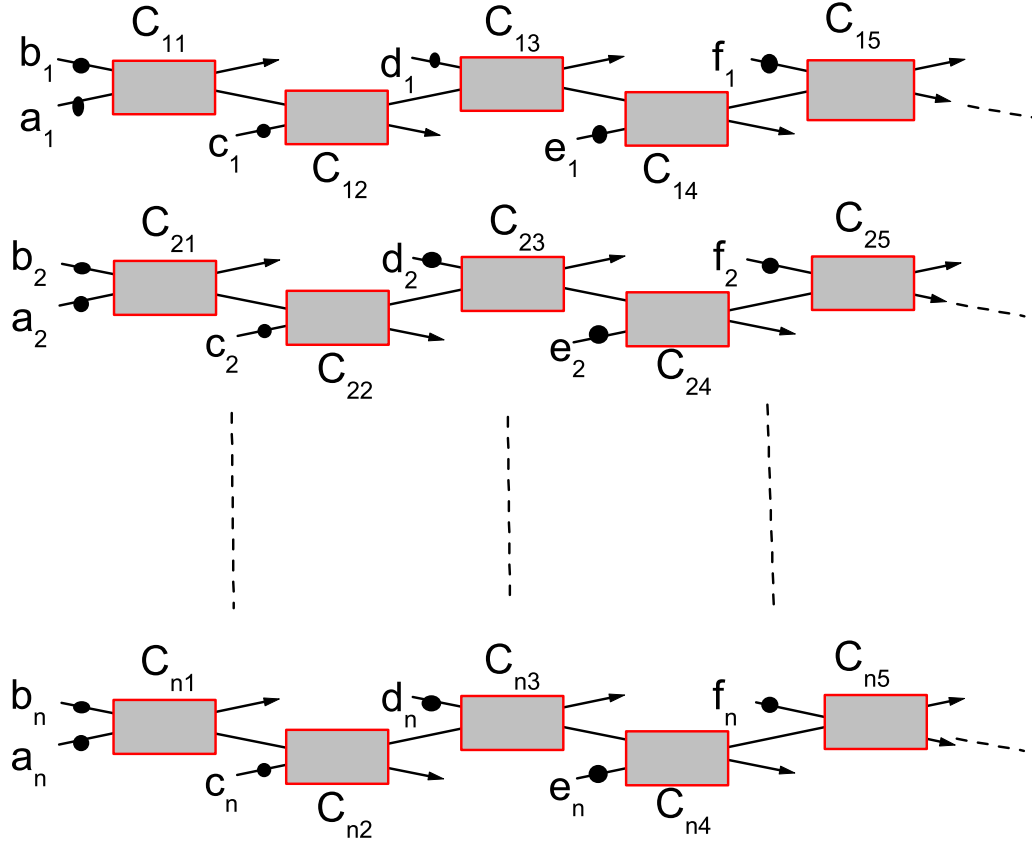


FIG. 4: The network for transfer of an arbitrary  $n$ -qubit state. See text for detail.

transferred successfully by using  $n - 1$  cavities in a network. As a matter of fact, in section 2 I have already shown that any arbitrary 2-qubit state can be transferred via using two cavities as a net work. Hence, in terms of recurrence one can easily conclude that any arbitrary  $n(n \geq 3)$ -qubit state can also be successfully transferred by using  $n$  cavities. According to this generalized scheme, a network for transfer of an arbitrary 2-qubit atomic state between atoms can be easily established (cf., figure 4).

## V. Summary

I have explicitly shown a transfer scheme that allows to faithfully and deterministically transfer an arbitrary  $n$ -qubit atomic state to an atom which is elsewhere. The perfect transfer is realized by letting two atoms interact simultaneously with a cavity QED. Since the large-detuned interaction between driven atoms and cavity is designed, the cavity is only virtually excited and accordingly the transfer scheme is insensitive to the cavity field states and cavity decay. Based on the scheme, a network for transfer of an arbitrary  $n$ -qubit atomic state between atoms is engineered.

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